United States Department of Agriculture | **Natural Resources Conservation Service** | **100 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: Soils -- Geophysical Assistance **Date:** 3 October 2008

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Purpose:
Electromagnetic induction (EMI) was used to help characterize the variability of soil and hydrologic properties within several vernal pools that are located in eastern Deschutes County. In addition, EMI was used to map and assess features within an Amphidrome septic system, which was recently installed at a home site in La Pine.

Principal Participants:
Bob Baggett, Oregon Department of Environmental Quality, Bend, OR
Laura Dlugolecki, Graduate Student, Water Resources Science, OSU Cascades, Bend, OR
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Mike Logan, Graduate Student, Water Resources Science, OSU Cascades, Bend, OR
Jen Moffitt, Range Specialist, BLM Prineville, OR
Kurt Moffitt, Soil Scientist, USDA-NRCS, Redmond, OR
Joe Page, Homeowner, La Pine, OR
Ron Rueter, Associate Professor, Department of Forest Resources, OSU Cascades, Bend, OR

Activities:
All field activities were completed during the period of 11 and 12 September 2008.

Summary:

1. Participants were exposed and had the opportunity to operate and conduct field surveys with a newly-developed EM38-MK2 meter.

2. The two vernal pool areas that were surveyed with an EM38-MK2 meter produced remarkably different EMI responses. The vernal pool at Playa # 295 had higher and noticeably more variable apparent conductivity (EC_a) than the one at Ram Lake NE. The vernal pool at Ram Lake NE, while having lower and less variable EC_a, had higher and noticeably more variable inphase data. These attributes suggest differences in hydropedologic properties between the two sites, which were both mapped as Swalesilver loam, 0 to 1 % slopes.

3. The large number of negative conductivity and inphase data recorded at the vernal pool sites are believed to be associated with the magnetic susceptibility (χ) of the soils and volcanic materials. It is

generally assumed that most profiled earthen materials are non-ferromagnetic and have very low or immeasurable χ. Because of the encountered difficulties in calibrating the EM38MK2 meter and the large number of negative responses recorded at the vernal pool sites, significant levels of magnetic susceptibility are considered probable (though not confirmed) in these areas of Swalesilver soils and volcanic deposits.

4. Results of EMI surveys of a newly installed and properly functioning Amphidrome septic system in La Pine showed slight differences in the measurements obtained with the newly-developed EM38-MK2 and the EM38-DD meters. With both meters, slight difference in measurements and resulting spatial patterns were observed with differences in the orientation of the traverse lines (essentially north-south versus east-west). Results suggest that either meter can be used to approximate EC_a across a septic system and produce closely similar but not identical measurements. The surveys at this site demonstrate the effective use of EMI to identify the locations of major septic-system components. As the investigated system was recently installed and not suspected of failure, the absence of a contaminant plume was anticipated.

It was my pleasure to work in Oregon and to be assistance to Ron Reuter.

With kind regards,

James A. Doolittle
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cc:
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Equipment:
The EM38-MK2 and EM38DD meters, manufactured by Geonics limited (Mississauga, Ontario), were used in this investigation.[1] The EM38-MK2 meter weighs about 2.8 kg (6.2 lbs) and requires only one person to operate. The EM38-MK2 meter operates at a frequency of 14,500 Hz. The meter has one transmitter coil and two receiver coils. The receiver coils are separated from the transmitter coil at distances of either 1.0 or 0.5 m. This configuration provides nominal penetration depths of 1.5 and 0.75 m (for the 1.0 and 0.5 m coil spacings, respectively) in the vertical dipole orientation and 0.75 and 0.38 m in the horizontal dipole orientation. Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2008). The EM38-MK2 meter can provide simultaneous measurements of both quadrature-phase (conductivity) and in-phase (susceptibility) components within two depth ranges.

The EM38DD meter consists of two, coupled EM38 meters. Each meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. This instrument weighs about 5.4 kg (11.9 lbs). Operating procedures for the EM38DD meter are described by Geonics Limited (2000). When placed on the soil surface, the meters provide nominal penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively. The EM38DD meter measures the apparent conductivity (EC_a) of earthen materials.

The coordinates of each EC_a measurement were recorded with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[1] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both EMI and position data.[1] The Trackmaker 38DD and TrackmakerEM38MK2 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EMI and GPS data.[1]

Vernal Pool Investigations:
Background:
Vernal pools are ubiquitous features in the rangelands of central Oregon. Typically, these pools are mostly dry, but fill with water after winter rains and/or snow melt. Vernal pools are considered wetlands and many constitute habits for several endangered species. The ecosystems of many vernal pools have been modified by range management practices, which include the excavation of stock watering dugouts. The use of electromagnetic induction (EMI) to characterize differences in soil and hydrologic properties within three vernal pools located in eastern Deschutes County was explored during this investigation.

Study Areas
The vernal pools are located in the eastern part of Deschutes County. Figure 1 contains the soil maps from the Web Soil Survey of sites 1 and 2. Both sites are located in areas mapped as Swalesilver loam, 0 to 1 % slopes (149A), and contain stock watering dugouts and embankment areas. The very deep, somewhat poorly drained Swalesilver soils formed in alluvial and lacustrine deposits derived from volcanic rocks and volcanic ash. Swalesilver is a member of fine, smectitic, frigid Aquic Palexeralfs soil taxonomic family. The particle-size control section of Swalesilver soils average 40 to 60 percent clay. Soil characterization data (Pedon ID: 96OR025007) shows horizons with clay contents ranging from 50 to 80 %. While, no ground-truth cores were extracted from the sites at the time of the EMI surveys, judging from the relatively low EMI responses measured over these sites, in my opinion, it is unlikely that these soils are fine textured.

As evident in Figure 1, Site 2 (Ram Lake NE) has a large, well defined vernal pool area, which includes a stock watering dugout. The vernal pool area at Site 1 has been largely altered, consisting mostly of the areas within a stock watering dugout and the surrounding spoil banks on either side of the structure.

Survey Procedures:
For each survey, the EM38-MK2 meter was operated in the deeper-sensing vertical dipole orientation. Data were recorded for both the 50 and 100 cm intercoil spacings. This provided nominal penetration depths of approximately 75 (50 cm spacing) and 150 (100 cm spacing). Both quadrature phase (conductivity) and inphase

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

data were collected. Conductivity data are expressed as values of EC_a in milliSiemens/meter (mS/m). Inphase data are expressed in parts per thousand (ppt). The EM38-MK2 meter was operated in the continuous (measurements recorded at 1-sec intervals) mode. Using the TrackmakerEM38MK2 program, both GPS and EC_a data were simultaneously recorded in an Allegro CX field computer. While surveying, the meter was held about 5 cm (about 2 inch) above the ground surface and orientated with its long axis parallel to the direction of traverse (see Figure 2). Surveys were completed by walking at a fairly uniform pace, in a random or back and forth pattern across each site.

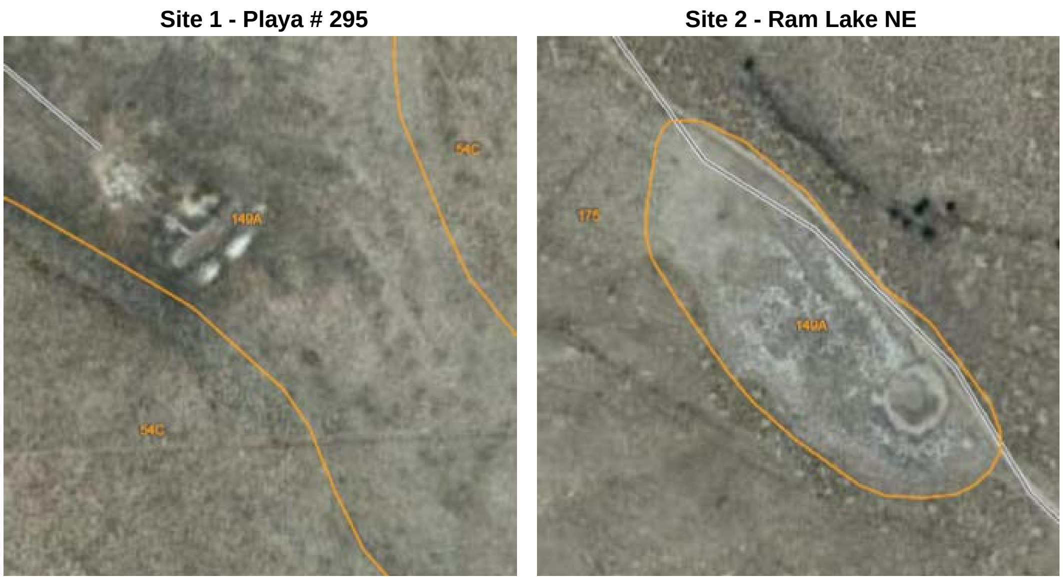

Figure 1. Soil maps of vernal pool sites 1 and 2.

Figure 2. Laura Dlugolecki (OSU Cascade) and Kurt Moffitt (USDA-NRCS) take turns conducting EMI surveys of vernal pools.

Calibration:

The EM38-MK2 meter was difficult to calibrate in the field. Similar experiences have been encountered over soils composed of very resistive earthen materials, which produce exceptionally low measured EC_a values. At each site, the meter was manually calibrated (nulling and instrument zero) following procedures described by Geonics Limited (Geonics Limited, 2008). During manual adjustments, it was observed that the 50 cm coil separation would not properly zero adjust; the horizontal measurement was always higher than the vertical dipole orientation (the vertical dipole should be twice the horizontal dipole measurement), which is improper. It is believed that the inability of the meter to properly calibrate reflects the mineralogy (and magnetic susceptibility) of the volcanic materials. At each site, following manual calibration, the meter was placed on a calibration stand for automatic instrument zero adjustments. The automatic calibration was used.

A large number of negative EC_a measurements were apparent in the data sets. Negative numbers are not in themselves uncharacteristic for EMI surveys, and can be attributed to some metallic artifacts scattered across sites. However, the large number of negative responses at Playa 2 seems anomalous and difficult to explain (other than by the suspected higher magnetic susceptibility of the soils).

The large number of negative conductivity and inphase measurements are believed to be associated with the magnetic susceptibility of the soils and the volcanic materials. Typically the use of EMI focuses on the electrical properties of soils and other earthen materials, and neglects magnetic properties. In areas of moderate to high electrical conductivity, EC_a dominates the measured EMI response. Magnetic susceptibility (χ) may affect the data, but its effects will be significantly less than the effects of EC_a, and will not as a rule be noticed in the data. In most areas, it is generally assumed that the profiled earthen materials are non-ferromagnetic and have very low or immeasurable χ.

Magnetic susceptibility is a parameter of soils and earthen materials that is responsive to the presence of ferromagnetic materials. Many rocks and minerals are weakly magnetic and, in response to an applied magnetic field, can be magnetized, producing what are know as “spatial perturbations” or “anomalies” in the earths magnetic field. A magnetometer can be used to measure magnetic susceptibility. The magnetic properties of soils principally reflect the effects of soil mineralogy (Magiera et al., 2006). Soils with manifested magnetic properties are generally dominated by ferromagnetic minerals, maghemite, magnetite, and/or titanomagnetites (Mullens, 1977). Parent materials strongly influence soil magnetic susceptibility as either the source of lithogenic magnetic materials or the matrix that favors the formation of magnetic materials (Hanesch and Scholger, 2005). Lithology exerts a most profound effect on the magnitude of χ (Singer et al., 1996). Shenggao (2000) observed that the absolute value and profile distribution of χ in soils is strongly influenced by lithology. Shenggao (2000), in a study of χ in China, concluded that the magnitude of soil χ follows a lithologic procession of: basic igneous rocks (basalt, andesite, and granodiorite) > neutral and acid igneous and metamorphic rocks > sedimentary rocks.

Magnetic susceptibly varies at all spatial scales and levels of resolution. In most soils, magnetic susceptibility is very low and is generally ignored. Because of the difficulties experienced in properly calibrating the EM38MK2 meter and the large number of negative responses, measurable levels of magnetic susceptibility are considered probable (though not confirmed) at the survey sites.

Results:

Table 1 lists some statistical results of the EMI surveys that were conducted with the EM38-MK2 meter operated in the vertical dipole orientation at Playa #295 (columns 2-4) and Ram Lake NE Playa (columns 6-9). These two vernal pool areas are remarkably different in terms of there EMI responses. Playa # 295 had higher and noticeably more variable EC_a than the Ram Lake NE. Ram Lake NE, while having lower and less variable EC_a, had higher and noticeably more variable inphase data. These attributes suggest differences in soil properties between the two sites, which were both mapped as Swalesilver loam, 0 to 1 % slopes. While values of EC_a are seldom diagnostic in themselves, in any given soil, a distinct range of conductivity should be measured. This is not the case for these two vernal pool areas, which are both mapped as Swalesilver loam, 0 to 1 % slopes (149A).

Table 1. Basic statistics for the EMI surveys conducted with the EM38-MK2 meter operated in the vertical dipole orientation at Playa #295 and Ram Lake NE. Apparent conductivity and inphase data are expressed in mS/m and ppt, respectively.

	Playa 295	**Playa 295**	**Playa 295**	**Playa 295**	**Ram Lake**	**Ram Lake**	**Ram Lake**	**Ram Lake**
Inter coil spacing and measurement	*100 cm mS/m*	*50 cm mS/m*	*100 cm ppt*	*50 cm ppt*	*100 cm mS/m*	*50 cm mS/m*	*100 cm ppt*	*500 cm ppt*
Number	1285	1285	1285	1285	1758	1758	1758	1758
Minimum	5.86	-15.94	-79.18	-250.08	-7.97	-57.4	-8.67	-154.03
25% tile	11.91	7.89	-53.48	-202.81	1.68	-21.7	38.75	-24.50
75% tile	31.17	19.96	-38.87	-176.25	7.66	16.5	66.84	18.82
Maximum	68.2	49.73	-8.79	117.27	29.46	6.89	152.00	148.24
Average	22.46	15.23	-46.23	-189.87	5.10	-18.96	53.28	-3.26
Std. Deviation	15.98	11.94	10.35	19.45	4.92	4.78	24.49	38.71

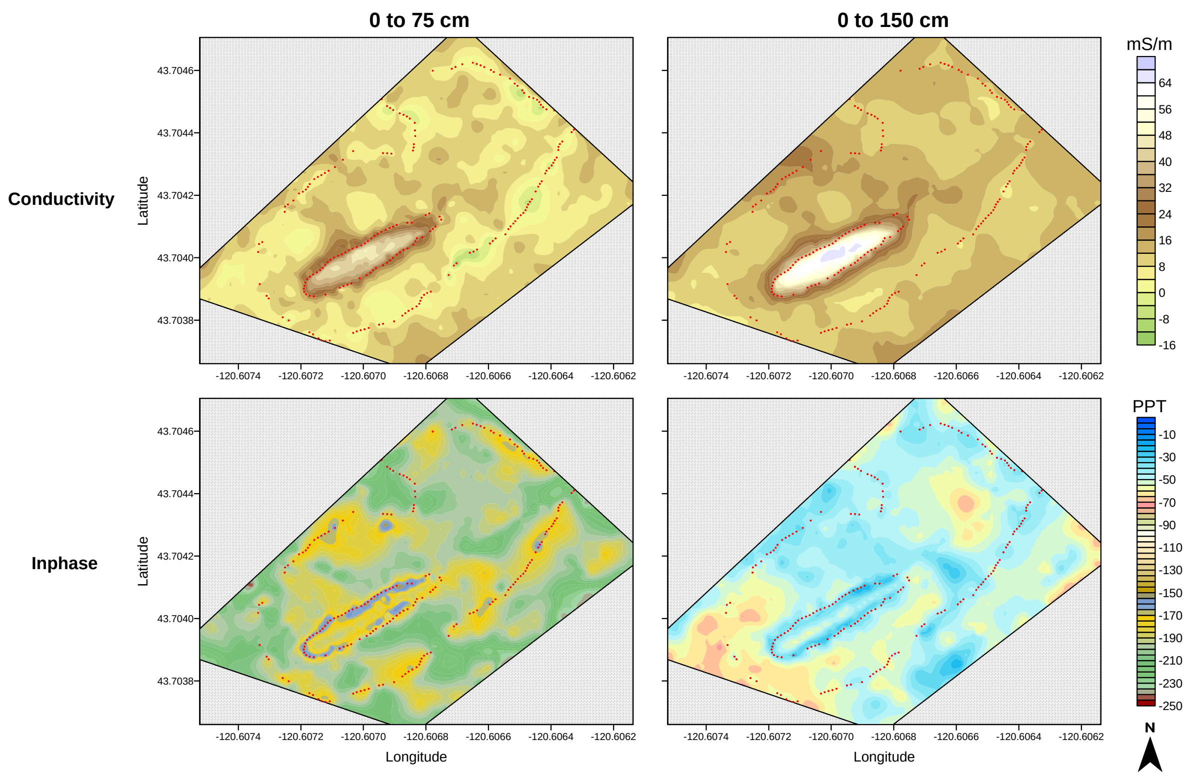

Figure 3. Spatial distribution of conductivity (top) and inphase (bottom) data collected with the EM38-MK2 meter at Playa #295. Plots show data for the shallower-sensing 50 cm (left-hand) and the deeper-sensing 100 cm (right-hand) intercoil spacings.

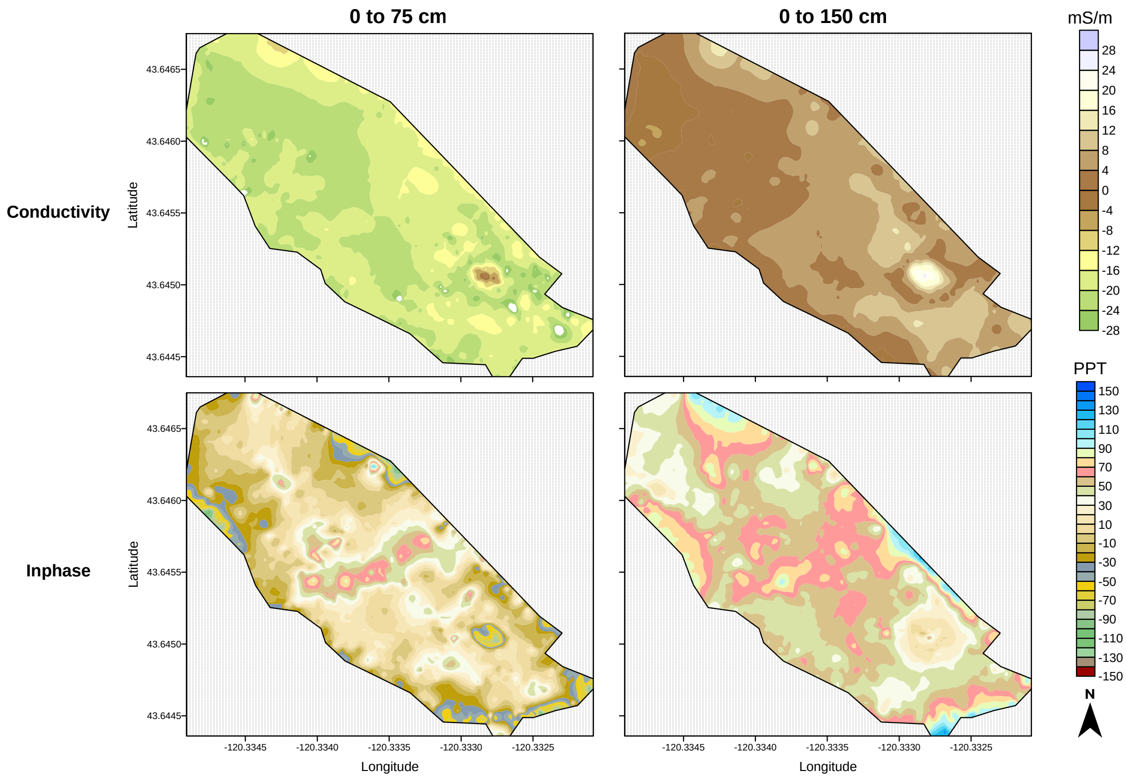

Figure 4. Spatial distribution of conductivity (top) and inphase (bottom) data collected with the EM38-MK2 meter at the Ram Lake NE. Plots show data for the shallower-sensing 50 cm (left-hand) and the deeper-sensing 100 cm (right-hand) intercoil spacings.

Figures 3 and 4 show plots of EMI data collected with EM38-MK2 meter at Playa #295 and Ram Lake NE, respectively. Different scales have been used for conductivity and inphase data at each site. In each plot, the dry, stock-watering dugout has anomalously higher EC_a and conspicuous inphase measurements. At Playa # 295, red-colored segmented lines have been used to distinguish vegetation zone boundaries (inner zone is dominated by knot grass weed; middle zone is dominated by silver sage and represents the maximum extent of the vernal pool; outer zone is dominated by mountain sage). The inner zone represents the excavated dugout. This zone is characterized by higher EC_a and is surrounded by a broad and difficult to defined transition zone.

All EMI data were entered into an Excel spreadsheet, a copy of which has been forwarded to Dr. Reuter. The EC_a data recorded on the Excel spreadsheet were processed thru the ESAP Software Suite program (Lesch et al., 1995a, 1995b, 2000). One of the statistical programs available in ESAP is the Response Surface Sampling Design (RSSD). This program generates an optimal sampling design based on the EC_a data. The optimal sampling design supposedly provides the best possible information for generating predictive models of soil properties. Based on the response surface sampling design, six optimal sampling locations were selected within the two surveyed vernal pool sites. A buffering procedure was not used, and, as a consequence, many of the soil sample sites were located near the boundaries of the survey areas.

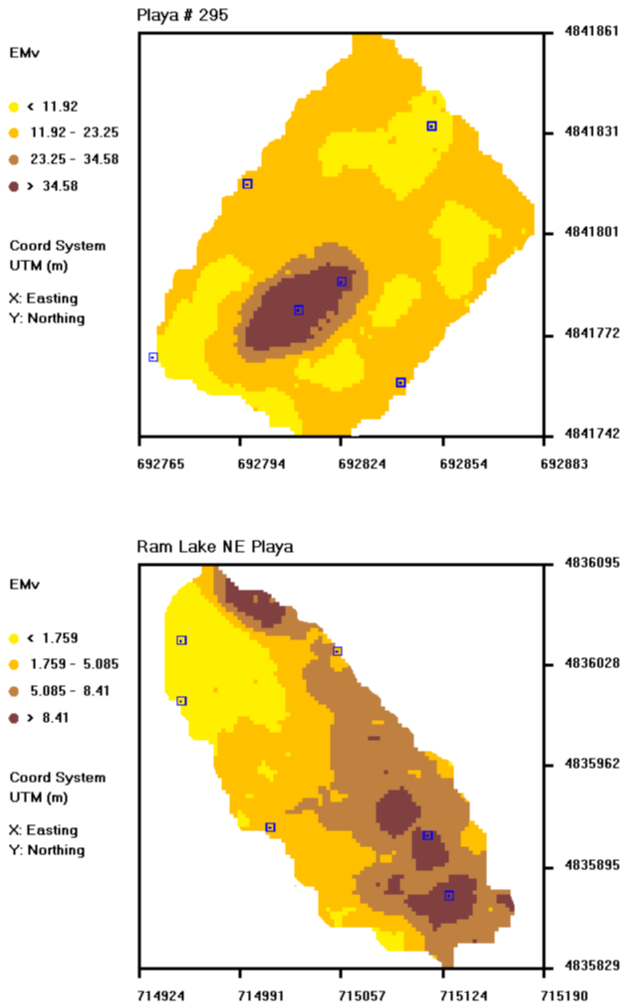

Figure 5. Plots of EMI data collected at Playa #295(upper) and Ram Lake NE (lower) showing spatial EC_a patterns and the locations of the ESAP derived optimal sampling locations.

The sampling points selected within each survey area are listed in Table 2. These points may be considered if additional sampling is required to characterize these sites. Sampling site selection is based on a Response Surface Sampling Design (RSSD). In Table 2, the coordinates and EC_a of each sampling point are listed.

Table 2. Sampling Point Data fort he two investigated vernal pool areas based on the ESAP program and a Response Surface Sampling Design (RSSD).

Playa	Observation #	Longitude	Latitude	EC_a
Playa 295	29	692796.41	4841816.57	23.09
Playa 295	59	692768.75	4841765.66	6.25
Playa 295	103	692841.24	4841757.88	19.22
Playa 295	241	692811.22	4841779.49	65.04
Playa 295	577	692823.82	4841787.60	48.2
Playa 295	1044	692850.30	4841833.56	6.84
Ram Lake NE	115	715054.32	4836038.24	5.08
Ram Lake NE	306	715010.52	4835922.10	4.53
Ram Lake NE	890	715127.96	4835877.13	12.35
Ram Lake NE	1062	714951.59	4836045.01	-2.26
Ram Lake NE	1346	715113.94	4835916.81	17.27
Ram Lake NE	1663	714951.58	4836005.05	-7.03

Septic System at La Pine:

According to a U.S. Geological Survey investigation, increased residential development and inappropriate septic systems in La Pine has led to increase nitrate concentrations in the ground water that drains into the Deschutes and Little Deschutes Rivers in southern Deschutes County. In an attempt to reduce this vulnerability, the La Pine Sewer District is expanding municipal water and sewer systems and providing landowners credits for not installing septic systems on their property. In this study, detailed grid surveys were conducted with two EMI meters over a newly installed, residential Amphidrome ® system in La Pine. The system is operating properly and no failure is suspected.

Study Site:

EMI surveys were conducted on land owned by Joe Page, a resident of La Pine (121.5306 ^{o} west longitude, 43.6696 ^{o} north latitude). The study site is located within an area of Sunriver sandy loam on 0 to 3 % slopes. The very deep, somewhat poorly drained Sunriver soils form in reworked ash deposits over older alluvium on stream terraces. Sunriver is a member of the ashy over loamy, glassy over mixed, superactive Aquic Vitricryands taxonomic family.

Mr. Page has recently installed an Amphidrome ® system in his backyard. The system is designed to pass batches of wastewater from an anoxic/equalization tank through a granular biological filter into a clear well. After this sequence is completed, the flow is reversed by a pump. The reverse flow passes from the clear well back through the filter. Any overflow from the filter is carried back into the anoxic/ equalization tank. The separate units of this system process wastewater in "batches" and discharge each treated batch of wastewater into a filter field over a short period of time.

The Amphidrome® reactor consists of a stainless steel underdrain, support gravel, and the filter media. The underdrain is located at the bottom of the Amphidrome® reactor and provides support for the media and distributes liquids into the reactor. A layer of gravel (about 18" thick) is placed over the underdrain. Above the gravel is a bed of coarse, round silica sand. The system also consists of a septic tank, clear well tank, Amphidrome® reactor tank, and interconnecting and internal piping.

Survey Procedures:

Survey procedures were simplified to expedite fieldwork. Two parallel sets of orthogonal lines were laid out. These four lines defined the perimeter of a 15 by 10 m, rectangular grid area. Along each of these four lines, survey flags were inserted in the ground at intervals of 1 m. These flags served as grid line end points and provided ground control. A rope line was stretched between similarly numbered flags on opposing sides of the grid. Surveys were conducted by walking at a fairly uniform pace with an EMI meter along this reference rope. This rope was sequentially moved and stretched across the grid area as the radar operator completed each traverse. Traverses were completed in a back and forth pattern across the grid area.

The EM38-DD and EM38-MK2 meters were used in this study. The meters were held about 1 to 2 inches above the ground surface with their long axis parallel to the direction of traverse. Each meter was operated in the continuous mode with two measurements recorded per second. For each meter, two separate surveys were completed along the orthogonal sets of grid lines. During post-processing of the EMI data, for each traverse line, the location of each measurement was adjusted using processing software to provide a uniform interval between observation points.

Results:

Basic statistics for the EC_a data collected with the EM38-MK2 and EM38-DD meters are shown in Tables 3 and 4, respectively. In Table 3, data is listed for the EM38-MK2 meter according to the direction of traverse (see first row) and intercoil spacing (see second row). The nominal depth of penetration is 75 cm and 150 cm for the 50 and 100 cm intercoil spacings, respectively. In Table 4, data is listed for the EM38-DD meter according to the direction of traverse (see first row) and dipole orientation (see second row). The nominal depth of penetration is 75 cm and 150 cm in the HDO (horizontal dipole orientation) and the VDO (vertical dipole orientation), respectively.

Table 3. Basic statistics for the two EMI surveys that were conducted with the EM38-MK2 meter operated in the vertical dipole orientation at the septic system study site in La Pine. With the exception of the number of observations, all values represent EC_a and are expressed in mS/m

Direction of travel	15-m axis	15-m axis	10-m axis	10-m axis
Intercoil Spacing	*50 cm*	*100 cm*	*50 cm*	*100 cm*
Number	435	435	452	452
Minimum	-35.86	-24.76	-11.80	-23.83
25%-tile	7.66	5.08	7.97	3.75
75%-tile	17.73	18.87	17.73	17.81
Maximum	196.33	446.76	382.19	543.59
Average	18.83	22.36	22.23	12.27
Standard Deviation	28.82	47.66	38.12	51.69

Table 4. Basic statistics for two EMI surveys that were conducted with the EM38-DD meter at the septic system study site in La Pine. With the exception of the number of observations, all values represent EC_a and are expressed in mS/m

Direction of travel	15-m axis	15-m axis	10-m axis	10-m axis
Dipole Orientation	*HDO*	*VDO*	*HDO*	*VDO*
Number	524	524	581	581
Minimum	-33.25	-78.86	-19.18	-74.75
25%-tile	2.88	3.88	2.38	3.62
75%-tile	12.25	20.75	11.25	15.12
Maximum	208.12	144.12	237.62	202.62
Average	13.88	17.13	13.50	14.88
Standard Deviation	29.29	25.62	28.34	26.41

In general, average EC_a values were slightly higher and the data sets were more variable for measurements collected with the EM38-MK2 meter than with the EM38-DD meter. Only slight difference can be observed with differences in the direction of travel and the orientation of the traverse lines. These results suggest that either meter can be used to approximate EC_a across the septic system and produce closely similar but not identical measurements. Measurements and spatial patterns will vary slightly with the orientation of the traverse lines. Slight differences in meter calibration, coil spacings and orientations, and traverse line positioning can account for the inconsistency noted in this study.

Figures 6 and 7 show spatial EC_a patterns collected with the EM38-MK2 meter and the EM38-DD meter, respectively. In each plot, Amphidrome system components that were evident on the soil surface have been located and identified. Regardless of the meter used or the directions in which the data were collected, spatial patterns are similar. Metallic objects, such as the solid waste tank, are good conductors, which produce anomalously high (positive) or low (negative) EMI responses as the meters cross over them. The locations of the solid tank, effluent tank, and the filter field (lower left hand corner of each plot) are identified by anomalous EC_a values. However, the smaller vent and valve boxes, and the vertically installed cylindrical amphidrome are not clearly detectable from EMI data alone.

The surveys at this site demonstrate the use of EMI to identify the locations of major septic-system components. As the investigated system was recently installed and not suspected of failure, the absence of a contaminant plume is not surprising. To be useful, the EMI data must be stable, accurate, precisely positioned, and collected after a suspected failure, but before the implementation of corrective measures. Acquisition of EMI data prior to construction could improve the diagnosis of any subsequent failure and, thus, the effectiveness of remediation.

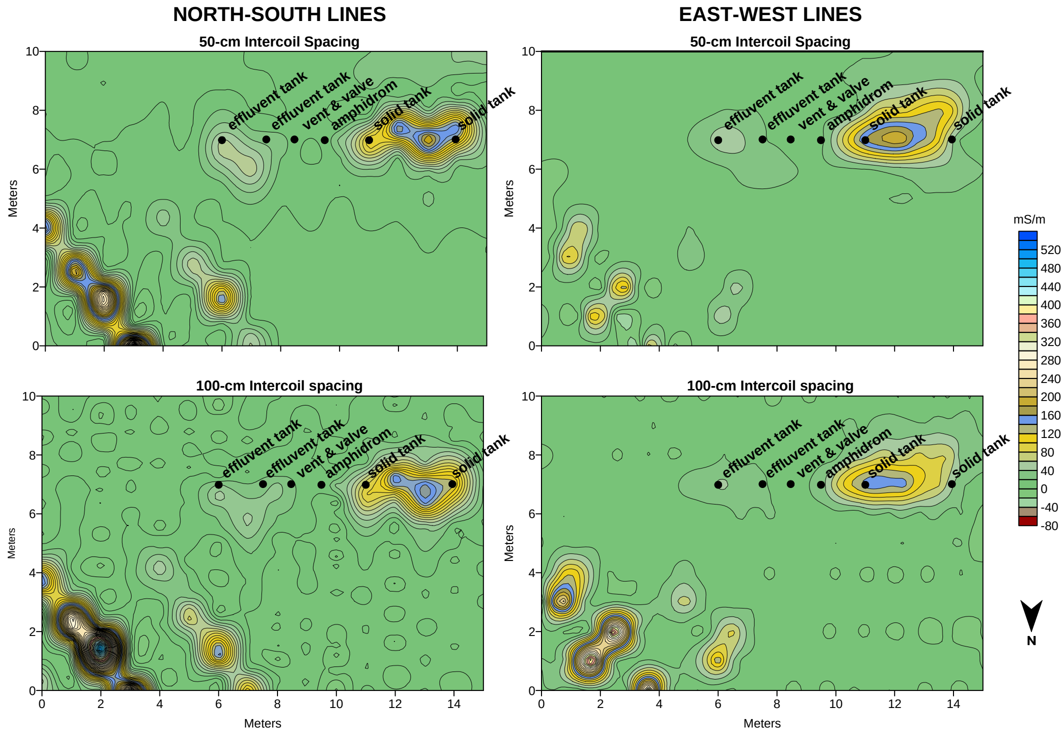

Figure 6. Spatial patterns of EC_a (top) and inphase (bottom) data collected with the EM38-MK2 meter at the study site in La Pine. Plots show data collected along north-south (left) and east-west (right) trending grid lines for shallower-sensing 50 cm (upper) and deeper-sensing 100 cm (lower) intercoil spacings.

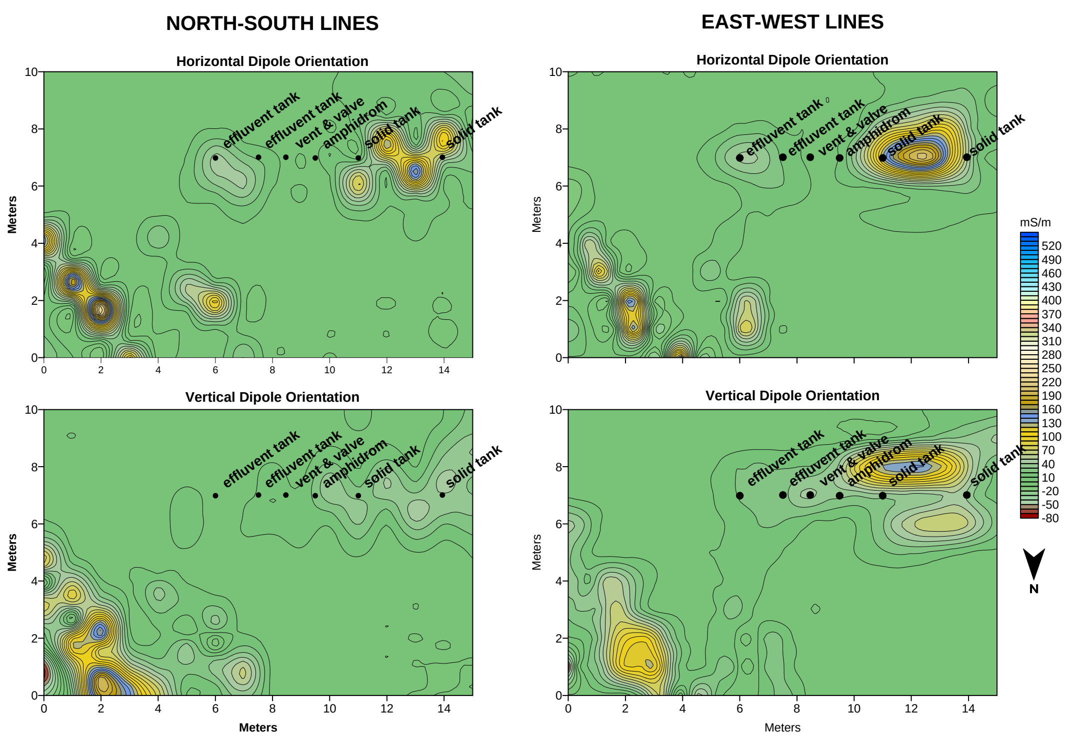

Figure 7. Spatial patterns of EC_a (top) and inphase (bottom) data collected with the EM38-DD meter at the study site in La Pine. Plots show data collected along north-south (left) and east-west (right) trending grid lines for shallower-sensing horizontal (upper) and deeper-sensing vertical (lower) dipole orientations.

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